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Mapping regulating services in Marrakesh Safi region - Morocco

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ABSTRACT Mapping ecosystem services (ES) has become an important tool to study nature's contributions to people (NCP) spatially and to manage ecosystems sustainably. However, few of these studies have been carried out in Africa and even fewer in drylands. This is not surprising, as drylands in general have not received much attention in the field of ecosystem services due to the perception that they do not provide much due to their low levels of productivity. In addition, not much data is available to map ecosystem services in Africa. In this study, we map regulating services of the Marrakesh Safi region in Morocco. First, a land cover map was developed based on existing information. This land cover map was thereafter used to map and model three regulating service categories in the region namely, carbon sequestration, microclimate regulation, and hydrological services (water regulation and water quantity) using six indicators. Our results show that agricultural land, which occupies the largest percentage area, also sequestered the most carbon in the study area. Forests sequestered about 16% carbon despite occurring in only 14% of the area and are the most efficient in sequestering carbon when considering carbon sequestered per hectare per year. The ecosystem type with the highest potential to supply water regulation services was Quercus ilex with about 200 m3 /ha. The study shows that the hotspots areas are located in the southeast parts of the study area where the Quercus ilex is mostly found. Contrary to the belief that most arid systems are not productive and therefore do not provide many ecosystem services, our spatial outputs showed that the area around Marrakesh in Morocco, despite being arid provides many regulating services including water and microclimate regulation.

1. Introduction

Global initiatives geared towards the sustainable use of ecosystems to support human wellbeing require that ecosystem services (ES), which are the benefits humans derive from nature be made spatially explicit. Examples where such spatial representation would be useful include in the recently endorsed Sustainable Development Goals (SDGs) of the 2030 Agenda for Sustainable Development, Convention on Biodiversity (CBD), United Nations Convention to Combat Desertification (UNCCD) and Intergovernmental Panel for Biodiversity and Ecosystem Services (IPBES). Several mapping studies have been initiated to support these initiatives (Burkhard et al., 2013; Crossman et al., 2013; Egoh et al., 2008; Maes et al., 2013; Willemen et al., 2017). According to Hauck et al. (2013a) maps are a powerful communication tool that can be used to improve the targeting of policy measures, by serving as support for legal documents, and in some cases may create agreements between stakeholders and authorities. In addition, maps can be used in planning and management processes in order to better understand the values or trade-offs that arise from land cover and land use changes (e.g. Egoh et al., 2008, 2011; O’Farrell et al., 2011). The special issue on the mapping and assessment of ecosystem services in the journal of Ecosystem Services aimed at responding to the needs of developing methods for mapping and modeling ES (Willemen et al., 2015). Several other studies also confirm that decisions about natural resources would be more effective, efficient and defensible when based on spatially explicit quantification of ecosystem services (Haines-Young et al., 2012; Nelson et al., 2009; Raudsepp-Hearne et al., 2010). While there has been, an overflow of mapping approaches developed and mapping of ecosystem service studies around the world, Africa appears to be left behind both in terms of marine and terrestrial ecosystem service mapping (Costanza and Kubiszewski, 2012; Egoh et al., 2012a; Liquete et al., 2013). In many areas of the world, including Africa, drylands have particularly been neglected in this field of study, because of low productivity and perceived limited ecosystem services. This perception is not necessarily true as many drylands have exotic species and ecosystems that provide unique services (Egoh et al., 2016). Indeed, these regions have higher demand for ecosystem services than most humid areas. Arid and semiarid regions of Africa are particularly limited in spatial and temporal information partly due to lack of resources. Another factor that has caused the lag in spatial modeling of ES in Africa is this limitation of data availability. While data exist for most provisioning services, information needed to map regulatory services is limited and often reduced to land cover (Egoh et al., 2012a). For the arid and semiarid regions, water regulation is central for agricultural production as well as sustainable water supply in streams. Similarly, micro-climate is of great importance as temperatures are projected to rise with a changing climate which may add stress on agricultural production and water use. One of the most important data layers required for ES mapping is land cover (Egoh et al., 2012a). Indeed, Burkhard et al. (2009) propose a new method for mapping ecosystem services based on land cover integrity using expert knowledge. However, most existing land cover maps are coarse scale of broad categories (e.g. forest, urban, grassland) of cover without necessary specification of different vegetation types. More detailed information on land cover such as forest types can be useful as different vegetation types play different roles in the ecosystem. Some models used to map ecosystem services such as the Agricultural Catchments Research Unit model (ACRU), require more detail difficult to measure information such as monthly values of the water use coefficient, the fraction of active plant roots in the topsoil zone and the daily rainfall reference evaporation (Warburton et al., 2010). Land cover information in Africa is limited and existing data covers very broad land cover categories. For example, the land cover map produced by Mayaux et al. (2004) has fewer than 30 classes for the whole of Africa with most of North Africa classified as desert. There is therefore a need to create land cover maps at finer local scale to provide more precise ES mapping. In this study, we developed a local scale land cover map for the region of Marrakesh Safi (Fig. 1), using compilation of available information. The land cover map was thereafter used to model and map three categories of regulating services in the region: 1) carbon sequestration, 2) microclimate regulation (using evapotranspiration, ground temperature, and canopy temperature) and 3) hydrological services: water quantity, and water regulation. We explicitly differentiate how each vegetation types contribute to the indicators used in measuring the delivering of these three service categories. Finally, we identify hotspots for these services where planning should be carried out to prioritize management. The ES were chosen to reflect on Morocco's strong interest and involvement in climate change, its future impact in the country and how it may affect ecosystem service delivery. This dryland region remains vulnerable to climate fluctuations and may see changes in temperature and rainfall which could have significant implication for the limited productivity of the landscape and consequently on water

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availability for the millions of people who live in this area (Niang et al., 2014). Regulating services are one of the most mapped services around the world (Egoh et al., 2012a), particularly in Africa due to the importance of regulating services such as water for food production and infiltration for flood attenuation (Egoh et al., 2012b). However, no study we know of, has mapped regulating services in northern Africa as most of the studies are in southern and eastern Africa. For an arid region, water regulation is crucial for agricultural production, erosion control as well as maintaining the flow of water in streams. Similarly, microclimate regulation is of great importance as temperatures in this region can rise as high as 40 °C in summer. These high temperatures will be exacerbated by climate change making microclimate regulation an important ecosystem service. Planting trees for their shading (shortwave radiation reduction) and evaporative cooling is a simple ‘means’ in the hand of urban planners to mitigate thermal stress in the climate regions with long and warm summers (Erell et al., 2011; Shashua-Bar et al., 2011) but this service can be provided by natural areas. Tree species can mitigate the soaring of temperature through carbon sequestration and storage but they can also provide microclimate regulation for regions such as Morocco. 2. Study area The Marrakesh Safi region is one of the twelve regions of Morocco covering about 5% of the total area of Morocco with 39,167km2 (Fig. 1) and a population estimated at 4 million inhabitants (RGPH, 2015). The climate of the region is semi-arid to arid, except for the High Atlas Mountains at an altitude between 1500 m and 2000m where the climate is considered as humid (MI, Monograph of the region, 2015). The annual rainfall in the study area ranges between 800 mm in the mountainous region to 190 mm in the lowlands. Marrakesh Safi is one of Morocco's most important areas in terms of biodiversity (Fennane, 2004; Fennane and Ibn Tattou, 1994). It houses a large number of endemic fauna and flora including close to 423 endemic plants (Fennane, 2004), many of them are on the IUCN “International Union for Conservation of Nature” red list (Baillie et al., 2004). Toubkal National Park, the largest national park in Morocco, is located in the South of Marrakesh Safi and considered as an important biodiversity hotspot and corridor of the Mediterranean basin (Dernegi, 2010). The main ecosystems in this region include forest, agro-ecosystem, continental fresh water and marine and coastal ecosystem. In this study, we focus on the terrestrial ecosystem, which consists mainly of forest and agro-ecosystem. The forest ecosystem covers an area of about 500,000ha, of which about 8% is plantation, found mostly in the High Atlas Mountains in the South of the region (HCEFLCD, 2005). The most important forest types in the study area are: Quercus ilex [Quercus rotundifofia] (157,660ha) also known as evergreen oak, Thuja [Tetraclinis articulata] (136,960 ha) and Argania [Argania spinosa] (132,910 ha) (Table 1). The Agro-ecosystem is considered the most important ecosystems in the region for its agricultural potential in both Bour (rainfed) and irrigated agricultural practices. The agricultural land occupies up to 51% of the region with cereals being the dominant crop. H. Ghazi et al. Journal of Arid Environments 159 (2018) 54–65 55 3. Material and methods 3.1. Land cover map development There was no proper land cover map for the study area when we initiated the study. We therefore developed a land cover map over the region using National Aeronautics and space administration's (NASA) Moderate Resolution Imaging Spectro-radiometer (MODIS) land cover classification (MCD12Q1) at 500 m × 500 m spatial resolution (Friedl et al., 2010) as base map and corrected and completed it using local data from the forest ecosystem map of Morocco (HCEFLCD, 2005), the irrigated areas and Dams (DIAEA, 2013) and ancillary satellite imagery (ESRI et al., 2013). We used ArcGIS10 to manipulate the MODIS classification map and contrasted it with local forest mapping obtained from HCEFLCD (2005). We also used the regional map of irrigated areas (DIAEA, 2013) to assert agricultural lands. In all cases local information was considered to be more accurate than MODIS classification and was thus imposed on the final product with the broad biome forest classes from MODIS reclassified using known local species. The process led to a new land cover map at the same horizontal resolution of 500 m hereafter referred to as Hybrid Map (Fig. 1). The hybrid map consists of a total of 6 land cover classes including water (inland water bodies including lakes and dams), forest (consisting of four subclasses: Quercus ilex (Evergreen oak), Thuja, Argania and mixed forest class), shrublands (representing areas with scattered vegetation consisting essentially discontinuous shrubs and woody vegetation), the agriculture class contains two subclasses: rain-fed agriculture (Bour) and irrigated agriculture, the urban class consists of all constructed areas within urban areas and the bare soil class refers to land with sparse vegetation. We aggregated the land cover map from 500 m spatial resolution to a climate modeling grid (CMG) of 25 km × 25 km over which the climate data are available every hour. The reconstructed product provides a gridded dataset in a CMG over the study region with each CMG having up to 6 land cover classes (Fig. 1) along with their fractions within the CMG obtained from higher resolution at 500 m. For each of the land cover classes in the CMG a set of biophysical parameters is mapped for 23-time periods representing a 16-day composite annual cycle for the vegetation phenology. The Hybrid land cover map along with the set of biophysical parameters are used as boundary and lateral conditions to the Simple Biosphere model used in this study to compute the turbulent exchanges of carbon, energy and water fluxes. 3.2. The model We used the “Simple Biosphere Model” (SiB2) (Sellers et al., 1996; Bounoua et al., 2009) to compute the variables relevant to the provision of the selected ecosystem services. SiB2 is a biophysically-based soil Table 1 The percentage area of different forest types (species) of Marrakesh Safi region. Specie % Area (ha) Quercus ilex 31.6% Thuja 27.4% Argania 26.6% Juniper 11.4% Matorral 0.8% Pine 0.4% Others 1.8% Total (ha) 100.0% Fig. 1. Hybrid Map of Land Cover of Marrakesh Safi Region. The area is dominated by agriculture and shrublands, while forest are located in the South. H. Ghazi et al. Journal of Arid Environments 159 (2018) 54–65 56 vegetation transfer model that computes the exchanges of carbon, energy and water, between the land surface and the atmosphere, using12 vegetation types including urban areas. The model also accounts for hydraulic and thermal properties of different soil types and use a coupled photosynthetic-conductance model to simulate the simultaneous exchange of carbon intake and water vapor diffusion. The model uses land cover map, soil and topography maps, but also tables of time-independent parameters which characterize the physiological, optical, and morphological properties of the vegetation and soil (Sellers et al., 1996). The model was fed with satellite-based biophysical data and it was driven by hourly climate data. The climate drivers were obtained from the Goddard Earth Observing System data assimilation system (GEOS-5) (Reichle et al., 2011) and bias-corrected using observations from meteorological stations in the study area. The model has been used in multiple studies to assess the impact of urbanization on surface temperature (Bounoua et al., 2009, 2015, 2017; Lachir et al., 2016; Zhang et al., 2016), to study physiological effects of doubled atmospheric CO2 on vegetation (Bounoua et al., 1999, 2000) and also for studying effects of land cover conversion on surface climate (Bounoua et al., 2002; Al-Hamdan et al., 2016). The model outputs several variables related to climate, soil and vegetation. However, in this study we consider only the following model outputs as indicators relevant to characterize the selected ecosystem services: i. Carbon assimilation to estimate the net carbon sequestration by different vegetation types, ii. Canopy water interception loss, canopy transpiration, ground interception loss and ground evaporation loss to estimate the amount of water used to capture the carbon

(Evapotranspiration) + Ground and canopy temperatures to estimate the contribution of ecosystems on microclimate regulation iii. Runoff outputs to calculate the contribution of each ecosystem on hydrological services (water quantity & water regulation) Most models use already available data instead of generating new ones (Kandziora et al., 2013), similarly the parameters used in this study were extracted from Bounoua et al. (2014) who quantified the amount of irrigation in semi-arid regions including Morocco. The resolution of the climate data available was 25 km, and we therefore aggregated all other data to the same resolution. In order to understand the extent of each land-cover type in each pixel, we also aggregated the pixels of hybrid map which had a resolution of 500 m into 25 km to match the resolution of the climate data. We also reclassified the land cover classes in the hybrid map to match those of the model as shown in Table 2. Finally, we calculated for each pixel of 25 km the fractions of each class of the hybrid land cover in percentage. 3.3. Mapping ecosystem services Ecosystem services are assessed over the region of Marrakesh-Safi using six indicators, namely: the carbon sequestration, represented by the net carbon assimilation (uptake minus respiration); The impact of evapotranspiration on surface temperature (canopy and ground temperature)- referred to hereafter as ‘microclimate regulation’; Finally, the impact of runoff on the hydrological services (water quantity and water regulation) is examined. 3.3.1. Carbon sequestration Climate regulation is always expressed through carbon sequestration or carbon storage. It is one of the most studied ecosystem service since it provides a global benefit by reducing atmospheric CO2, although most studies have mapped carbon stocks rather than sequestration (Crossman et al., 2013). It refers to the amount of carbon uptake by plants from the atmosphere and stored within its tissues. Since this is a continuous process over time, the assimilation of CO2 is measured in the model as µmoles/m2 /sec. To let the mass of carbon sequestration comparable we had to change the unit to grams of Carbon using the following equation: Assim of C (g/pixel) Assim (i,j) * % classe (i,j) * Mc * Pa*H*D*Y = (1) where: Assim (i,j): the assimilation of CO2 in the pixel (i,j) (moles/m2 / sec); % class (i,j): percentage of the vegetation type in the pixel (i, j); Mc: molar mass of carbon = 12 g/mole; Pa: pixel area (ha) = dx (m) *dy (m)*cos(lat)/10000; H: number of second in an hour = 3600; D: number of hours in a day = 24; Y: number of days in a month = 30. 3.3.2. Microclimate regulation Ecosystems contribute to climate regulation at different scales. At a larger scale, natural vegetation reduces greenhouse gasses from the atmosphere mitigating climate change. At the local scale, natural vegetation modifies weather patterns such as temperature, air humidity and wind speed. This local service is called microclimate regulation, which maintains the temperature balance at the soil surface, improving conditions for decomposition of organic matter and release of soil nutrients (Murray et al., 1990). Many studies on microclimate based on radiation measurement or micrometeorological measurement have proven already that shading is the most effective way to moderate summer heat stress. (Égerházi et al., 2013, Égerházi and Kovács, 2014; Mayer, 2008; Mayer et al., 2008; Takács et al., 2015). In our study, we mapped microclimate regulation, which can be defined as the role of nature in regulating temperature at a local scale using evapotranspiration. Vegetation plays an important role in microclimate regulation through albedo and evapotranspiration change. Plants release water vapor (necessary for cloud formation) and absorb and emit energy, which in turn impacts on the weather. Vegetation thus creates microclimate by regulating the humidity and temperature locally. To map the service of microclimate regulation, we used two key parameters as indicators from SiB2 outputs: Evapotranspiration and temperature. The importance of evapotranspiration in microclimate regulation can be explained in two ways. First, it is the largest factor, which together with precipitations influences water balance. Thus, equations related to water balance are reliant on vegetation dynamics and characteristics. Secondly evapotranspiration influences the temperature (Zhang et al., 2001). In this study, we modeled evapotranspiration as the amount of water used to capture the carbon with four input data namely, the canopy water interception loss (ECI), canopy transpiration (ECT), ground interception (EGI) and ground evaporation (EGS). The following equation was used: Evapotranspiration ECT ECI EGS EGI (Watt/m =++ +)2 (2) Evapotranspiration is presented as flow with the unit watt/m2 in the model output. To know the exact amount of water used in the Table 2 Equivalent of land cover classes of Hybrid map and SiB2. Hybrid map classes Equivalent SiB2 Classes Water T00: inland water Forests T06: broadleaf trees with groundcover Agriculture Bour T07: Groundcover Agriculture Irrigated T12: broadleaf deciduous trees with winter wheat Urban T08: urban/built up Shrublands T09: broadleaf shrubs with bare soil Bare soil T11: no vegetation: Bare soil H. Ghazi et al. Journal of Arid Environments 159 (2018) 54–65 57 evapotranspiration in m3 as unit we need to change the unit from watt to mm of water as follows: 1 W = 0,035 mm H2O/day according to Allen et al. (1998). To calculate the Evapotranspiration by each pixel in m3 we use the following equation: Evapotranspiration (m /pixel) Evapo (W/m) * % class(i,j) * Pa * a * 10* 3 2 = M (3) where: Evapo W/m2 = ect + eci + egs + egi (w.m-2); a: equivalent evaporation 1 W/m2 = 0,035 mm/day; % class(i,j): percentage of the class in the pixel (i, j); Pa: pixel area (ha) = dx (m) *dy (m)*cos(lat)/ 10000; 10: 1 mm = 10 m3 /ha; M: number of days in month. As mentioned above, the model provides as outputs two types of temperatures, both ground and canopy temperature in degree Celsius as unit. 3.3.3. Hydrological ecosystem services As described by Bounoua et al. (2009) water from the surface layer can either evaporate or infiltrate into the root zone layer from which it can flow up back to the surface layer and therefore if infiltrated into the deep layer, it can be used by plants for transpiration, or simple resurface to contribute to runoff. In this study, we mapped hydrological services as the amount of water not used by the plant (transpiration) nor evaporate at the soil level but runs through the land and available for use. The models and indicators available for mapping hydrological services range from simple basin-scale water balance functions that link precipitation, actual and potential evapotranspiration, land cover and soil water holding properties to complex, spatially-explicit processbased hydrological models that simulate daily runoff calibrated using long-term daily precipitation and stream gauge data (Crossman et al., 2013; CSIRO, 2008). Here we differentiate between water quantity (Surface Runoff) and water regulation. 3.3.3.1. Water quantity. In the model, surface runoff is seen as a negative parameter because it can cause inundation. However, as most ecosystem services the capacity to provide the service is determined by the availability of the service. Therefore, surface runoff is considered as an indicator for water supply and availability. Several studies have used runoff as a proxy for water supply (Egoh et al., 2012a). Runoff is a simple indicator of water quantity, which indicates how much water is available for various uses (e.g. household use, irrigation and recreation) as most of the runoff ends in river systems or other water bodies. The output for surface runoff from the model is in meters (m). We therefore converted the output into m3 . The following equation describes how the conversion was carried out. Water quantity (m /pixel) srf_runoff (m)* 1000 * % class (i,j) * Pa * 10 3 = (4) where: 1 m = 1000 mm; % class (i,j): percentage of the class in the pixel (i, j); Pa: pixel area (ha) = dx (m) *dy (m)*cos(lat)/10000 and 10: 1 mm = 10 m3 /ha. 3.3.3.2. Water regulation. Water regulation is the amount of water, which infiltrates to feed the underground water table. We calculated water regulation as total runoff (output of SiB2) minus surface runoff (water quantity) (Eq. (4)).

We also changed the unit of total runoff from meter to cubic meter (m3) to match those of surface runoff (Eq. (4)). 3.4. Identifying the hotspots The concept of hotspots was first initiated by Myers et al. (2000) more than two decades ago (Mittermeier et al., 1999) who identified biodiversity hotspots around the world where conservation efforts should be focused. Since the concept of ecosystem services surfaced, the concept of identifying hotspots of ecosystem service provision is only beginning to gain attention. One of the first studies to identify ecosystem services hotspots was Egoh et al. (2008) partly based on the definition of Myers et al. (2000) in the 1980s on hotspots of species and refers to areas which provide large proportions of a particular service, and do not include measures of threat or endemism. Generally, there is no consistent definition of ecosystem services hotspots available in the literature (Schroter and Remme, 2016), and some studies define the ES hotspots by incorporating threat as indicator while others don't (Schroter et al., 2017). In this study, we consider hotspots as the areas, which offer the highest levels of ecosystem services mapped. In mapping hotspots, we used the three categories of services already mapped: carbon sequestration, hydrological services (water quantity and water regulation) and microclimate regulation (using only evapotranspiration as main proxy). We used the "hotspot index" to develop the hotspot map. To do this, we normalized the indicators representing the three categories of services studied with values between 0 and 1 and then overlay them by considering the whole range. Then we produced the hotspot index by adding the scores of normalized services representing the 3 categories of services in one raster applying equal weight scheme. The produced raster has pixels values ranging between 0 and 4 (since there were two indicators for hydrological services, water quantity and water regulation) where the score of 4 represent areas with high number of services and 0 represent areas with low number of services. 4. Results 4.1. Carbon sequestration Our results show that about 55% of all carbon sequestration occurs during the spring months between February and May, with the least sequestration occurring between August and October. Agricultural land is the largest land class in the study area and it is not surprising that it sequestered the largest amount of carbon (65%) followed by shrublands (18%). The forest ecosystem sequestered about 16% carbon despite occurring in only 14% of the study area. Forest land cover was also more efficient in sequestering carbon when considering carbon sequestered per hectare per year with 2.01 t of C/ha compared to 1.98 t of C/ha for Agriculture (Table 3). Indeed, the forest type "Quercus ilex" which is made of broadleaf evergreen oak trees sequesters almost Table 3 Monthly carbon sequestered in each land cover class in Marrakesh Safi region measured in tons per hectare (t C/ha). Month Shrublands Forests Agriculture Urban Bare soil 1 0.11 0.20 0.24 0.006 0.006 2 0.14 0.21 0.36 0.010 0.014 3 0.17 0.28 0.47 0.017 0.025 4 0.16 0.41 0.41 0.022 0.039 5 0.12 0.31 0.22 0.019 0.032 6 0.04 0.20 0.06 0.016 0.012 7 0.02 0.12 0.03 0.015 0.010 8 0.02 0.06 0.02 0.013 0.009 9 0.02 0.05 0.03 0.010 0.007 10 0.02 0.03 0.03 0.007 0.005 11 0.03 0.04 0.04 0.003 0.002 12 0.06 0.09 0.07 0.003 0.002 Total per year 0.90 2.01 1.98 0.14 0.16 H. Ghazi et al. Journal of Arid Environments 159 (2018) 54–65 58 4tC/ha/year (Fig. 2) higher than any other land cover type. Rain-fed agriculture also sequestered an important amount of carbon (2t C/ha/ yr) more than the shrublands and the other forest types. The peak of carbon sequestration seems to occur in March generally, but for the Argania ecosystem the peak is in the month of January, due to the flowering period, which begins generally in autumn (Bani-Aameur, 2002). The carbon sequestered in the southeastern parts of the region (where Quercus ilex is located) is more than in the southwest (Fig. 3). Also in the northwest, where the bour agriculture is present there's significant sequestration. 4.2. Microclimate regulation Microclimate regulation is a function of evapotranspiration (Fig. A. 1) and temperature (Fig. A. 2). Our results show that temperature is mostly low where the evaporation/transpiration is higher and vice versa (Fig. A. 3). This is not surprising as evapotranspiration influences temperature. However, Fig. 4 shows high evapotranspiration in both the north western and south eastern parts of the country but the spatial patterns mostly supports the existence of this negative correlation. The peak of evaporation/transpiration is in early spring, which corresponds to the modest temperatures during the year. 0 0.5 1 1.5 2 2.5 3 3.5 4 t/ha Land Cover Class Carbon SequestraOon (t/ha) Fig. 2. Carbon sequestration by different land cover classes (t C/ha/year). Fig. 3. Carbon sequestration in Marrakesh Safi (t C/ha/year). The zone with higher amount of sequestration is represented by darker shade, the lighter shade represents the lowest area providing carbon sequetsration H. Ghazi et al. Journal of Arid Environments 159 (2018) 54–65 59 4.3. Hydrological ecosystem services 4.3.1. Water quantity Our results show that surface runoff is highest in urban areas with 150 m3 /ha (Fig. 5). This represents 3% of the surface runoff in the study area while this class occupied less than 1% of the total area. The total runoff in the study area according to the model results’ is equal to 603 Mm3 /year. In contrast to surface runoff, bare soil with shrubs has the highest total runoff with 300m3/ha (Fig. 5). 4.3.2. Water regulation In the study area, the ecosystem that provides the most water regulation is the agricultural areas (Fig. A. 4) with about 150m3/ha, the ecosystem with high capacity to provide water regulation services in the study area is Quercus ilex with 200m3/ha (Fig. 5). The mapping of the water supply in Marrakesh Safi region (Fig. 6) clearly shows that the southeastern parts of the study area (zone of Quercus ilex forest and agriculture) is most important for water regulation, but represents the lowest provision for water quantity even if this zone is dominated by mountains. This result highlights the role that forests can play in water recharge. Fig. 4. Spatial variations between a) evapotranspiration (m3 /ha) b) ground temperature (°C) c) canopy temperature (°C) in Marrakesh Safi Region. Dark shade indicates high microclimate regulation. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.) Fig. 5. The amount of water supply (water quantity and water regulation) compared with the total runoff by each land cover class in Marrakesh Safi region by m3 /ha. H. Ghazi et al. Journal of Arid Environments 159 (2018) 54–65 60 4.4. Identification of hotspots Hotspots in this study represent areas where we observed a maximum number of regulatory ecosystem services studied in the region of Marrakesh Safi (Fig. 7). The results show that the Southeastern part of the study area is an important hotspot in regulating services which also coincides with the areas of forests (especially Quercus ilex ecosystem) and irrigated agriculture (Fig. 1). 5. Discussion In this study, we set out to assess and map regulating ecosystem services in the Marrakesh-Safi Region of Morocco. According to Everard and Waters (2013), ecosystem service assessment is a useful tool in determining and communicating the broader risk of degradation of ecosystems on human wellbeing. Maps are particularly important because they can be helpful for spatially explicit decision-making and monitoring of the consequences of decisions particularly in the environmental sector Hauck et al. (2013a). Maps are also important in understanding what to do where in terms of management. Our results (Table 4) showed that both the Quercus ilex and Bour agriculture are important in delivering multiple ecosystem services considered in this study (Fig. 8). Several studies have shown the importance of biodiversity and in particular forests in delivery ecosystem services such as carbon sequestration leading to the United Nations' initiative on reducing emissions from deforestation and forest degradation (REDD) (Keith et al., 2009). Although these studies were not focused on arid areas, trees in general, including Quercus ilex have been shown to have a greater ability to store carbon. In contrast, agricultural areas have been mostly seen as degraded areas with no potential in providing services. In this study however, we have shown that agricultural areas can provide services particular in arid regions with low vegetation cover. In some part of morocco, such as the Agoudi N'Lkhir Municipality, most agriculture is traditional (bour) (Bouzekraoui et al., 2016). This type of agricultural practice may favour provision of ecosystem services than industrialized agriculture. In this case rain-fed agriculture should be the preferred option in order to promote the delivery of ecosystem services. Fig. 6. Spatial variation of hydrological services in Marrakesh Safi region: a) Total RunOff, b) Water quatity and c) Water Regulation. All services are represented by m3 /ha. The darker shade refers to the high services. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.) Fig. 7. Hotspots of ecosystem services in the Region of Marrakesh Safi. The highest index (dark shade) refers to the areas with high regulating services (hotspot), the lowest (light shade) refers to the area with less regulating services. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.) H. Ghazi et al. Journal of Arid Environments 159 (2018) 54–65 61 The land cover types related to Quercus ilex and Bour agriculture are mostly found in the southern and eastern parts of the study area also identified as a hotspot for ecosystem services. Policy measure to maximise multiple ecosystem services should be directed towards these two areas. The National Park of Toubkal (protected area) is located in the south, which could justify the establishment of a protected area in the region or the resulting effects of the protected area establishment. In fact, a number of studies have shown that often ES hotspots are especially located within the boundaries of natural protected areas (GarcíaNieto et al., 2013; Palomo et al., 2013; Spanòa et al., 2017). These results also demonstrate that human intervention is not always negative towards environmental benefits as seen in the case of bour agriculture. On the contrary, according to our research urban areas provided the least ecosystem services. According to Bounoua et al. (2009) and Lachir et al. (2016), urban areas are characterized by artificial surfaces, which cannot provide important regulation services. Also, among the vegetation types Argania ecosystems provide the lowest services. The very level of low regulating services provided by this ecosystem, can be explained by the range of distribution of this species, which is in an area with very low precipitation (less than 250 mm/year) compared to Quercus ilex which receives more than 500 mm/year. The findings of this study disprove the assumption that most arid systems are unproductive and incapable of providing important ecosystem services. Indeed, the carbon sequestration found in the forest areas of this study was 2.01 t C/ha/year and is comparable to those found in humid areas such as forest in Shenyang-China (humid continental climate), which was 2.84 t/ha/year (Liu and Li, 2012) and high than that of Hangzhou-China (1.66 t C/ha/year) where the climate is subtropical (Zhao et al., 2010). The lumping of the northern areas in Africa and classifying them as desert, may not reveal the potential of ecosystem service delivery in the region as demonstrated in this study using a finer vegetation map. Therefore, the development of detailed land cover/vegetation maps for the study area is an important output for future studies. While we have Fig. 8. Ecosystem services delivery by different ecosystems. The scale is from 0 (lowest service delivery) in the centre to the 5 (highest service delivery) towards the outside of the spider. Microclimate regulation was represented by evapotranspiration as the main indicator. Table 4 Summary of annual ecosystems services (based on six indicators) produced in Marrakesh Safi Region per hectare for each land cover class. Carbon Sequestration (t/ha) Microclimate regulation

Hydrological services Evapotrans-piration (m3/ha) Canopy Temperature (°C) Ground Temperature (°C) Water quantity (m3/ ha) Water regulation (m3/ha) Shrublands 0.90 1149.43 15.80 15.64 40.82 42.10 Mixed Forest 1.44 752.44 14.97 14.97 26.98 118.86 Thuja 1.61 850.21 15.83 15.86 41.46 106.20 Quercus ilex 3.67 1659.67 14.18 14.07 38.48 199.48 Argania 0.76 497.62 17.80 17.93 34.87 71.26 Irrigated Agriculture 1.61 780.62 15.38 15.39 24.55 100.36 Bour Agriculture 2.36 1259.03 15.31 15.27 54.82 154.28 Urban 0.14 81.08 15.60 14.90 150.94 89.89 Bare Soil 0.16 110.77 14.47 13.87 55.13 244.76

H. Ghazi et al. Journal of Arid Environments 159 (2018) 54–65 62

limited this study to regulating services in Morocco, the country and other northern African countries are well known for their tourism potential (cultural services) as well as other provisioning services such as olive farming. A detailed land-cover map would help in delineating several ecosystem services provided and the possible congruence and trade-offs that may arise in managing the landscape. The selection of appropriate spatial and temporal scales is a recurring challenge in practical application of ecosystem service science (Hauck et al., 2013b). Most ecosystem service mapping studies, have used popular software such as INVEST (Crossman et al., 2013). However, several other software and models, hold potential in mapping ecosystem services as shown in this study. We have used the "Simple Biosphere Model" (SiB2) (Sellers et al., 1996) to map regulating services in Morocco. While this model showed great potential and there are possibly other models available to be used in this field of study, our results should be interpreted with care for several reasons. First, the model was not developed for ecosystem service mapping and some parameters such as surface runoff are treated as negative parameters. Second, the level of uncertainty in the model is not well understood and finally, as with any model, adapting an existing model to answer a new question requires time for validation within the study area. While it is important to use any available information and model to map ecosystem services where information is not available, results must be considered carefully. However, the advantage of using such "Simple Biosphere Model" (SiB2) is that it is very detailed and more specific rather than other generalized models. Other limitations not mentioned above includes the density of the vegetation cover and the fact that for a socio-ecological field, demand for the services such as human pressure (population densities) were not taken into consideration.

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Appendix A. Supporting material Fig. A. 1. Evapotranspiration by land cover Classes by the unit of m3 per hectare per year. Fig. A. 2. Comparing the temperature of the soil (ground) and the canopy in each Land cover class by degre Cilsus (°C). Almost the two tempertures are equal except for the urban and the bare soil classes where the canopy temperature is very high than ground temperature.

H. Ghazi et al. Journal of Arid Environments 159 (2018) 54–65 63

Fig. A. 3. (a)Variation of Canopy Transpiration (ECI+ECT) by Million cubic meter (Mm3) compared to the Canopy temperature (°C) and (b)Variation of Ground evaporation (EGI+EGS) (Mm3) compared to the Ground Temperature (°C). Fig. A. 4. The water regulation service produced by each ecosystem (land cover class), presented by million cubic meter (Mm3) in Marrakesh Safi Region. Appendix A. Supplementary data Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jaridenv.2018.03.005.